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Title: **REAL-TIME DATA ACQUISITION AND TELEMETRY
BASED IRRIGATION CONTROL SYSTEM**

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1 **REAL-TIME DATA ACQUISITION AND TELEMETRY BASED**

2 **- IRRIGATION CONTROL SYSTEM**

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4 **CONTRACTUAL ORIGIN OF THE INVENTION**

5 This invention was made with United States Government support under Contract
6 No. DE-AC07-94ID13223, now Contract No. DE-AC07-99ID13727 awarded by the
7 United States Department of Energy. The United States Government has certain rights in
8 the invention.

9 **BACKGROUND OF THE INVENTION**

10 **Field of the Invention**

11 The present invention relates generally to methods and devices for facilitating real
12 time management of an object system. More particularly, embodiments of the present
13 invention relate to a data acquisition and telemetry control system for facilitating
14 substantially real-time control of automated irrigation systems.

15

16 **Prior State of the Art**

17 It is generally acknowledged that the availability of water for agricultural
18 applications is becoming an ever-increasing problem. The relative scarcity of water has
19 obvious negative consequences. For example, because the water is relatively scarce, the
20 price that is charged for the water that is available is relatively higher. This is in accord
21 with basic economic principles. Furthermore, it is a natural consequence of higher water

1 prices that the crops that are produced with that water will be more expensive, therefore
2 increasing the end cost to consumers for those agricultural products.

3 A variety of factors affect the supply of water used in agricultural applications.
4 Some factors, such as weather, are essentially uncontrollable. However, one of the most
5 significant, controllable, factors affecting the supply of agricultural water is the general
6 tendency of farmers to over-irrigate their crops. This problem is particularly acute where
7 farmers irrigate with center pivot irrigation systems. Some experts have estimated that
8 farmers using center pivots disperse up to thirty percent more water than is necessary to
9 support the development of the crop.

10 As suggested earlier, over-irrigating has economic consequences in that it tends to
11 reduce the overall water supply, and thus increase water costs. In addition to reducing the
12 overall water supply however, over-irrigating may also damage crops. For example,
13 some experts have noted that over-irrigating of potatoes tends to promote disease, and
14 reduce potato size and quality. There are other problems associated with over-irrigating
15 as well. In particular, farmers realize a significant outlay in costs associated with
16 pumping the water to and onto the agricultural fields. Over-use of water naturally
17 increases pumping costs to the farmer.

18 Clearly, over-irrigation has a variety of undesirable consequences, and yet the
19 practice continues. There are a variety of reasons for this. One of the reasons for over-
20 irrigation is that many farmers lack an economic incentive to do otherwise. For example,
21 the state of Idaho has over one million acres served by center pivot irrigation systems.
22 However, many farmers there own water shares and thus the water is relatively

1 inexpensive. Accordingly, those farmers have little economic incentive to conserve
2 water, and thus tend to use more water than they actually need.

3 Another reason for over-irrigation relates to the fact that the typical farmer's
4 watering scheme is essentially empirical in nature. It is generally acknowledged that
5 rates of water absorption and retention may vary widely throughout an agricultural field.
6 However, the farmer is forced to take a worst case approach and over-irrigate rather than
7 under-irrigate so as to ensure that those portions of the agricultural field that use water
8 most quickly are adequately watered and retain adequate moisture to support crop
9 development. Thus, because the farmer lacks any way to precisely determine the
10 differing water requirements of the various portions of the agricultural field, and to
11 disperse water accordingly, the farmer is forced to err on the side of over-irrigating rather
12 than under-irrigating.

13 As suggested in the foregoing discussion, one of the major factors contributing to
14 the scarcity of agricultural water is the tendency of farmers to over-irrigate their crops.
15 The major reason for over-irrigating is that farmers have no reliable, contemporaneous,
16 method or device to determine the moisture content throughout their fields. Farmers
17 would be able to much more readily control their water consumption, and associated
18 pumping costs, if they had a relatively inexpensive system and/or device which could
19 determine moisture content throughout the entire agricultural field and then communicate
20 that data to an irrigation control system. The benefits of such a system or device would
21 include increased water availability, reduced water costs, and improved crop quality.

1 While systems exist wherein desired data is communicated or transmitted to some
2 type of transmitter/receiver, those systems are inadequate to solve the problems identified
3 herein. In particular, these systems typically involve transmission of data that has been
4 embedded in a computer chip or the like. When a signal from the transmitter/receiver
5 impinges upon the chip, the chip transmits the embedded, or pre-programmed, data back
6 to the transmitter/receiver. However, these systems are inadequate to solve the problems
7 discussed herein because they suffer from the significant limitation that they cannot
8 acquire data, rather they simply transmit data that has already been pre-programmed.

9 Other known systems are capable of acquiring and then transmitting data.
10 However, these systems have limitations as well. A typical system employs a plurality of
11 sensors disposed in a particular environment so as to measure one or more parameters of
12 interest with respect to the environment. Upon interrogation by a transmitter/receiver, the
13 sensors acquire the desired data and transmit it to the transmitter/receiver. The major
14 shortcoming of such systems is that the sensors typically require a power source such as a
15 battery or the like, in order to acquire and then transmit data. Thus, such sensors are of
16 limited utility where replacement of the power source is impossible or impracticable.
17 Furthermore, power sources such as batteries are sensitive to temperature extremes and
18 other environmental influences that may compromise their performance or render them
19 ineffective. The problems associated with battery powered sensors and the like are
20 further exacerbated in those situations where a plurality of sensors are deployed. Finally,
21 these types of systems typically only gather and process data, they do not include
22 substantially real-time system control functionality.

1 It will be appreciated that, due to changing environmental, soil, and crop
2 conditions, the moisture content of an agricultural field may vary greatly with the passage
3 of time and according to different locations in the field. Due to the inherently dynamic
4 nature of the moisture content of a particular environment, any system or device for
5 measuring moisture content and transmitting moisture content data must be able to do so
6 continuously and reliably. Known systems lack the functionality to meet these
7 performance requirements.

8 In view of the foregoing problems with known irrigation methods and devices,
9 what is needed is a soil moisture sensor capable, upon demand, of measuring moisture
10 content of an area of interest, and transmitting the acquired moisture content data to a
11 data collection point. The soil moisture sensor should be able to process the collected
12 moisture content data to generate a moisture map. Further, the soil moisture sensor
13 should be able to continuously and contemporaneously update the moisture map.
14 Additionally, the soil moisture sensor should be able to communicate the moisture map to
15 an irrigation control system so as to facilitate substantially real-time irrigation system
16 control. Finally, the soil moisture sensor should be relatively inexpensive and easy to
17 maintain.

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19 **SUMMARY OF THE INVENTION**

20 The present invention has been developed in response to the current state of the
21 art, and in particular, in response to these and other problems and needs that have not
22 been fully or completely solved.

1 Thus, it is an overall object of the present invention to provide a soil moisture
2 sensor that resolves at least the aforementioned problems and shortcomings in the art.

3 It is another object of one embodiment of the present invention to provide a soil
4 moisture sensor that employs moisture content data to generate, and periodically update, a
5 moisture map of an agricultural field.

6 Finally, it is an object of one embodiment of the present invention to provide a
7 soil moisture sensor that operates in conjunction with an irrigation control system so as to
8 facilitate substantially real-time development and implementation of an irrigation plan for
9 an agricultural field.

10 In summary, the foregoing in other objects, advantages, and features are achieved
11 with an improved soil moisture sensor for use in contemporaneously determining
12 moisture content of various portions of the agricultural field. Embodiments of the present
13 invention are particularly suitable for use in facilitating precise irrigation of agricultural
14 fields by center pivot and linear move irrigation systems.

15 In a preferred embodiment, the improved moisture sensor includes a reader
16 capable of operative communication with one or more probes. Preferably, each of the
17 probes includes a biodegradable body substantially composed of cardboard or the like, so
18 as to minimize expense and to preclude the need for recovery of the probes at the end of
19 the growing season. Each probe employs circuitry that requires no internal power source
20 for operation, rather, as described below, the probe receives its power via an inductive
21 couple established between the probe and an energy source, or reader. Preferably, the
22 circuitry comprises digital electronics. The digital electronics of the probes include a

1 moisture sensitive capacitor disposed so as to be in operative contact with that portion of
2 the agricultural field whose moisture content is to be monitored.

3 In operation, the reader selectively emits an excitation signal, preferably
4 comprising both data and energy components, that is received by a probe
5 receiver/transmitter when the reader passes within a predetermined distance of the probe.
6 Preferably, the probe receiver/transmitter comprises a tuned circuit antenna so as to
7 facilitate maximization of energy exchange with the reader. The excitation signal is
8 passed within the probe receiver/transmitter to a system processor which, in turn, is in
9 operative communication with the moisture sensitive capacitor. The digital output, or
10 data, from the system processor serves to indicate the moisture content detected by the
11 moisture sensitive capacitor. This digital data is then transmitted to the reader via the
12 probe receiver/transmitter, and is received by the reader receiver/transmitter. As with the
13 probe receiver/transmitter, the reader receiver/transmitter preferably comprises a tuned
14 circuit antenna. Upon receiving the digital data transmitted by the probe(s), the reader
15 feeds the digital moisture content data to a control module in operative communication
16 with an irrigation system so as to facilitate substantially real-time control of field
17 irrigation.

18 These and other objects, features, and advantages of the present invention will
19 become more fully apparent from the following description and appended claims, or may
20 be learned by the practice of the invention as set forth hereinafter.

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BRIEF DESCRIPTION OF THE DRAWINGS

6 In order to more fully understand the manner in which the above-recited and other
7 advantages and objects of the invention are obtained, a more particular description of the
8 invention will be rendered by reference to specific embodiments thereof which are
9 illustrated in the appended drawings. Understanding that these drawings depict only
10 typical embodiments of the invention and are not therefore to be considered to be limiting
11 of its scope, the invention and its presently understood best mode for making and using
12 the same will be described and explained with additional specificity and detail through
13 the use of the accompanying drawings in which:

14 Figure 1 is a general arrangement schematic showing one embodiment of a soil
15 moisture sensor, and indicating generally the relation between the reader and the probe;

16 Figure 2A is a block diagram of one embodiment of an active style probe
17 employing digital electronics, and indicating relationships among various elements of the
18 probe;

19 Figure 2B is a block diagram of an embodiment of an active style probe
20 employing analog electronics, and indicating relationships among various elements of the
21 probe;

1 Figure 2C is a block diagram of an embodiment of a passive style probe
2 employing analog electronics, and indicating relationships among various elements of
3 the probe;

4 Figure 3A depicts one embodiment of a moisture sensitive capacitor;

5 Figure 3B depicts an alternative embodiment of a moisture sensitive capacitor;

6 Figure 3C depicts yet another alternative embodiment of a moisture sensitive
7 capacitor;

8 Figure 4A is a block diagram of one embodiment of a reader employing digital
9 electronics, indicating the relationships among the various elements of the reader;

10 Figure 4B is a block diagram of one embodiment of a reader employing analog
11 electronics, indicating the relationships among the various elements of the reader; and

12 Figure 5 depicts an embodiment of a data-acquisition-and-telemetry-based control
13 system; and

14 Figure 6 depicts use of a data-acquisition-and-telemetry-based control system in
15 an agricultural application.

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DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The agriculture industry, like many other industries, is becoming more sensitive to economic pressures. The misuse of resources can lead to higher costs, which in turn lead to lower profits. These economic pressures are addressed, in part, by focusing on systems and methods for not only reducing cost, but also increasing production and profitability. In particular, a significant cost faced by the agriculture industry is the cost of water. Not only does water have a monetary cost, but the ineffective use of water ultimately has detrimental effects on the yield and profitability of the crop being cultivated.

Irrigating a crop with too much water has a negative economic impact. For example, irrigating potatoes with too much water promotes disease, reduces potato quality, decreases potato size, increases storage cost and can lead to nitrogen leaching which increases fertilizer costs. Similarly, irrigating with too little water has a negative economic impact. The present invention is directed towards methods and systems than permit a particular agricultural field to be irrigated with an appropriate amount of water at the appropriate time. Frequently, the amount of irrigation is dependent on current water content of the field being irrigated. The present invention is described in terms of a center pivot irrigation system, but can apply to other irrigation systems as well as situations where water content or other fluid content is to be measured.

Reference will now be made to figures wherein like structures will be provided with like reference designations. It is to be understood that the drawings are diagrammatic and schematic representations of various embodiments of the invention, and are not to be construed as limiting the present invention.

In general, the present invention relates to an improved soil moisture sensor having data acquisition and telemetry functionality for use in determining moisture content of agricultural fields, and in employing the moisture content data to facilitate substantially real-time control of an irrigation system. Figures 1 through 6 indicate various embodiments of a moisture sensor conforming to the teachings of the invention.

Reference is first made to Figure 1 which depicts one embodiment of the present invention. The soil moisture sensor is depicted generally as 100 and includes, among other things, a data acquisition function to measure the moisture content of the soil, and

1 telemetry function wherein the moisture content data is transmitted and analyzed. Soil
2 moisture sensor 100 comprises a reader 200 and at least one probe 300. In a preferred
3 embodiment, a plurality of probes 300 are disposed throughout agricultural field 400, or
4 other zone of interest, so as to be in contact with soil 402. While Figure 1 indicates an
5 arrangement wherein a portion of probe 100 protrudes from soil 402, other arrangements
6 are contemplated wherein probe 100 is buried completely beneath the surface of soil 402,
7 as required to suit a particular application and/or probe configuration.

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8 As further indicated in Figure 1, one embodiment of probe 300 includes a body
9 301A supported by stiffener tube 301B. In one embodiment, body 301A is substantially
10 biodegradable and comprises cardboard or the like so as to facilitate production of an
11 inexpensive probe 300 and to preclude the need for recovery of probes 300 at the end of
12 the growing season.

13 The operation of soil moisture sensor 100 proceeds generally as follows. When
14 reader 200 passes within a predetermined distance of probe 300, reader 200 transmits
15 excitation signal 202 which is incident upon probe 300. Probe 300 is in operative
16 communication with reader 200 so that probe 300 collects energy from excitation signal
17 202 and stores that energy for future use. As discussed in greater detail elsewhere
18 herein, it will be appreciated that excitation signal 202 may also include data, including,
19 but not limited to, instructions for probe 300. Probe 300 then uses the energy thus stored
20 to gather moisture content data from soil 402 and transmit that moisture content data, in
21 the form of a data signal 302, to reader 200. It is thus an important feature of the present
22 invention that probe 300 requires no internal power source. Rather, due to an inductive

1 coupling established between reader 200 and probe 300, all of the energy required to
2 perform the data acquisition and transmission functions of probe 300 is supplied by
3 reader 200 via the inductive coupling. After data signal 302 is received by reader 200,
4 reader 200 stores the digital data from data signal 302. The moisture content data thus
5 acquired may be employed to facilitate real-time control of a field irrigation system,
6 wherein the amount of water dispensed on various parts of agricultural field 400, as well
7 as the time(s) at which the water is dispensed, are determined with reference to the
8 moisture content data. Alternatively, the moisture content data may be used to generate a
9 moisture map of agricultural field 400. Note that, as contemplated herein, "moisture"
10 refers generally to liquids and various combinations thereof, including, but not limited to,
11 water. Note further that soil 402 is but one example of a medium of interest whose
12 parameters could profitably be measured and/or monitored by embodiments of the
13 present invention. As discussed elsewhere herein, the measured values of those
14 parameters may be employed in variety of different ways.

15 The functionality provided by probe 300 can be achieved in a variety of different
16 ways. For example, the electronic circuit 303 (see Figure 2A, for example) utilized in
17 probe 300 could be either digital or analog. Note that, as discussed in further detail
18 below, the meaning of "electronic circuit" contemplated by the present invention
19 includes, but is not limited to, circuits employing signal processing and/or power
20 transmission functionality. Further, it is contemplated that such electronic circuits may
21 comprise digital or analog elements, or combinations thereof.

With continuing reference now to probe 300, probe 300 may employ an "active" mode of operation wherein probe 300 is capable of storing energy received from reader 200 and then transmitting a data signal 302 to reader 200 at a substantially different frequency, and time, than that of excitation signal 202. An alternative embodiment of probe 300 may employ a "passive" mode of operation, wherein no energy is stored, and data signal 302 is transmitted to reader 200 at substantially the same frequency or harmonic as that of excitation signal 202. Note however, that any device or system having the functionality of probe 300, as disclosed herein, is contemplated as being within the scope of the present invention.

A preferred embodiment of probe 300 is depicted in Figure 2A in block diagram form. In general, electronic circuit 303 of probe 300 is preferably digital and includes a power transmission element (generally indicated in phantom lines) and a signal processing and transmission element (generally indicated in solid lines). However, the two elements may in some instances be interconnected so that the portion of the circuit represented by a particular solid line or phantom line in Figure 2B may, at different instances, serve to transmit power as well as facilitate signal processing and transmission.

As indicated in Figure 2A, this embodiment of probe 300 includes a probe transmit/receive antenna 304 having a capacitor 305. Preferably, probe transmit/receive antenna 304 comprises a tuned circuit, antenna, i.e., a resonant antenna, or the like. Note that because probe receive/transmit antenna 304 is preferably sensitive to, and generates, a B-field, it does not radiate to an extent that would interfere with other radio frequency (RF) services.

1 It will be appreciated that a variety of means may be profitably employed to
2 perform the receive and transmit functions of probe transmit/receive antenna 304 and
3 reader transmit/receive antenna 204 (see Figure 4A and 4B). Probe transmit/receive
4 antenna 304 and reader transmit/receive antenna 204, respectively, are but examples of
5 means for receiving and transmitting signals. Thus, the circuits disclosed herein simply
6 represent embodiments of circuits capable of performing these functions. It should
7 accordingly be understood that these circuits are presented solely by way of example and
8 should not be construed as limiting the present invention in any way. An alternate
9 example of means for receiving and transmitting signals comprises transmit/receive coils
10 such as B-field generators, and the like.

11 As discussed in further detail below, probe transmit/receive antenna 304
12 facilitates establishment of an inductive couple between reader 200 (not shown) and
13 probe 300. Electronic circuit 303 additionally includes an input signal demodulator 306
14 in communication with a system processor 308. Specifically, system processor 308
15 includes an input 308A to which input signal demodulator 306 is connected, and an
16 output 308B connected to output signal modulator 310. Preferably, input signal
17 demodulator 306 and output signal modulator 310 are adapted for frequency
18 demodulation and modulation (FM), respectively. However, in an alternative
19 embodiment, input signal demodulator 306 and output signal modulator 310 are adapted
20 for amplitude demodulation and modulation (AM), respectively.

21 With continuing reference to Figure 2A, system processor 308 additionally
22 includes a drive output 308C and a sense input 308D, between which is connected a

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1 moisture sensing capacitor 312. As discussed elsewhere herein, there are a variety of
2 configurations that will provide the functionality of moisture sensing capacitor 312.
3 Moisture sensing capacitor 312, in turn, is in operative communication with soil 402.
4 Finally, electronic circuit 303 includes a rectifier 314 connected to probe transmit/receive
5 antenna 304 and to energy storage capacitor 316. Energy storage capacitor 316, in turn,
6 is connected to receive/transmit controller 318. Note that probe 300 may be inserted into
7 soil 402 so that only probe transmit/receive antenna 304 remains exposed, alternatively,
8 probe 300 may be buried completely underneath the surface of soil 402.

9 In operation, radio frequency (RF) energy is emitted by reader 200 (not shown) as
10 excitation signal 202 and is received at probe 300. At electronic circuit 303, the
11 incoming RF energy causes sufficient voltage to be built up there to produce a flow of
12 alternating current (AC). In one embodiment, excitation signal 202 comprises at least
13 two components, a data component 202A and an energy component 202B. In an
14 alternative embodiment, excitation signal 202 consists primarily of an energy component
15 202B.

16 Data component 202A preferably comprises a frequency modulated (FM) carrier
17 wave, but may alternatively comprise an amplitude modulated (AM) carrier wave. Note
18 that the present invention contemplates as within its scope data components 202A
19 modulated in other ways as well, such as by phase shifting. The present invention also
20 contemplates as within its scope data components 202A modulated in more than one way,
21 for example, a data component 202 modulated with respect to both amplitude and phase.
22 Generally, data component 202A comprises various desired instructions from reader 200

1 to probe 300. Exemplary instructions include guidance as to when probe 300 should
2 transmit data back to reader 200, how often probe 300 should transmit data to reader 200,
3 or whether probe 300 should report diagnostic information.

4 With continuing reference to Figure 2A, excitation signal 202 impinges upon
5 probe transmit/receive antenna 304. Energy from energy component 202B is built up in
6 capacitor 305, in the form of a potential difference, until such time as sufficient energy is
7 stored to put rectifier 314 into operation. When rectifier 314 is thus activated, it serves to
8 rectify, or convert, the incoming AC current, received by probe transmit/receive antenna
9 304, into direct current (DC) which is then used to charge energy storage capacitor 316 to
10 a predetermined voltage.

11 After energy storage capacitor 316 has been charged to the predetermined voltage,
12 preferably about five (5) volts, and energy component 202B has ceased to be transmitted,
13 these conditions are sensed by the receive/transmit controller 318 which then switches
14 from 'receive' mode to 'transmit' mode. In particular, receive/transmit controller 318
15 allows current to flow from energy storage capacitor 316 to system processor 308 and
16 output signal modulator 310. In the event excitation signal 202 includes a data
17 component 202A, receive/transmit controller 318 allows power to flow from energy
18 storage capacitor 316 to input signal demodulator 306 as well.

19 The power stored in energy storage capacitor 316 and subsequently released by
20 way of receive/transmit controller 318 is used for several different purposes. First, in the
21 case where excitation signal 202 includes a data component 202A, power from energy
22 storage capacitor 316 is used to energize input signal demodulator 306 so that input

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1 signal demodulator 306 is able to demodulate the modulated data signal 202A prior to
2 reception by system processor 308. Preferably, the output from input signal demodulator
3 306 to system processor 308 comprises a digital data signal carrying particular
4 instructions for system processor 308 relating to the gathering and/or transmission of
5 moisture content data.

6 Energy storage capacitor 316 also provides power to energize system processor
7 308. Upon being energized, system processor 308 sends a drive signal from drive output
8 308C to moisture sensing capacitor 312 which, in response, acquires soil 402 moisture
9 content data. As discussed elsewhere herein, one embodiment of moisture sensing
10 capacitor 312 comprises a hydrophilic dielectric which absorbs moisture to a level
11 consistent with the surrounding soil 402, so that the response of moisture sensing
12 capacitor 312 to the drive signal produced by system processor 308 is an analog
13 waveform representing the moisture content of soil 402 in the vicinity of moisture
14 sensing capacitor 312. This arrangement also provides a way to measure the soil matrix
15 water potential if the relationship between the water content and potential are known for
16 the particular dielectric. Moisture sensing capacitor 312 thus serves as a sensor of
17 variable capacitance that, when energized, exhibits a capacitance that is characteristic of
18 one or more parameters of the medium to which the moisture sensing capacitor 312 is
19 exposed. The analog signal produced by moisture sensing capacitor 312 is then returned
20 to system processor 308 by way of sense input 308D, whereupon system processor 308
21 converts the analog signal to a digital carrier signal.

1 The digital carrier signal thus produced by system processor 308 then passes to
2 output signal modulator 310 for modulation preparatory to transmission of moisture
3 content data to reader 200 (not shown). Note that, as contemplated herein, "modulation"
4 refers to the general process whereby data is superimposed on a carrier signal, so as to
5 form a data signal, by modification of one or more of the characteristics of the carrier
6 signal, the aforesaid characteristics of the carrier signal including, but not limited to,
7 phase, amplitude, and frequency. In similar fashion, "demodulation" refers to the
8 extraction of data from a modulated signal.

9 In a preferred embodiment, output signal modulator 310 modulates at least the
10 frequency of the digital carrier signal produced by system processor 308. Thus, the
11 frequency of the carrier signal used to form data-signal 302 transmitted by probe 300 can
12 be adjusted so as to be materially different than that of excitation signal 202. As
13 discussed in greater detail below in the context of reader 200, this is a valuable feature
14 because it allows reader 200 to transmit at frequencies substantially different from those
15 at which it receives, thereby minimizing interference at reader 200 and improving reader
16 200 performance. Also, receive/transmit controller 318 preferably serves to ensure that
17 data signal 302 will be transmitted at a materially different time than excitation signal
18 202. Finally, note that one or more of the operations of system processor 308 may be
19 performed in response to instructions carried by a data component 202A of excitation
20 signal 202.

21 While frequency modulation is one way to modulate the digital carrier signal
22 produced by signal processor 308, so as to produce data signal 302, it will be appreciated

1 that various other parameters of the digital carrier signal, including, but not limited to,
2 phase and amplitude, may be modulated as well by output signal modulator 310, either
3 alone or in various combinations. Such modulation is accordingly contemplated as being
4 within the scope of the present invention. Data signal 302 is then transmitted to reader
5 200 by way of probe transmit/receive antenna 304.

6 As suggested earlier, an alternative embodiment of an "active" mode probe 300
7 employs analog circuitry. One such embodiment is indicated generally as 300A in Figure
8 2B. In particular, electronic circuit 303 of probe 300A includes a receive/transmit coil
9 304A, and a variable frequency oscillator (VFO) 320 having a moisture sensing capacitor
10 312 which serves to control the frequency at which VFO 320 oscillates.
11 Receive/transmit coil 304A preferably comprises an inductive loop or the like so that, in
12 operation, probe 300A is inductively coupled to reader 200 via receive/transmit coil
13 304A. As further indicated in Figure 2B, electronic circuit 303 also comprises a rectifier
14 314A, an energy storage capacitor 316A, and a receive/transmit controller 318A.

15 In operation, reader 200 passes within a predetermined distance, preferably about
16 ten (10) feet, of probe 300A and transmits excitation signal 202 which impinges upon
17 probe receive/transmit coil 304A. Note that in this embodiment, excitation signal 202 is
18 primarily composed of energy component 202B, and does not include a data component
19 202A. Excitation signal 202 preferably comprises RF energy. As a result of the
20 transmission of excitation signal 202 by reader 200, a voltage is gradually developed in
21 probe receive/transmit coil 304A so that a flow of AC current is produced which flows to
22 rectifier 314A. The flow of AC current is converted to DC current by rectifier 314A, and

1 the DC current then serves to charge energy storage capacitor 316A. Over the course of
2 many cycles of excitation signal 202, the voltage across energy storage capacitor 316A
3 builds up to a predetermined level, preferably about five (5) volts, but in any event, a
4 voltage level adequate to facilitate the data gathering and data transmission functions of
5 probe 300A.

6 When the voltage in energy storage capacitor 316A reaches the predetermined
7 level, receive/transmit controller 318A switches electronic circuit 303 of probe 300A
8 from 'receive' mode, wherein voltage is built up in energy storage capacitor 316A, to
9 'transmit' mode. In 'transmit' mode, energy storage capacitor 316A discharges, producing
10 a flow of current that energizes VFO 320 and thereby causes VFO 320 to emit a signal of
11 characteristic frequency, or oscillate. The signal thus produced is data signal 302. As
12 previously noted, the frequency at which VFO 320 oscillates is controlled by moisture
13 sensing capacitor 312. In particular, the capacitance of moisture sensing capacitor 312,
14 which is a function of the moisture content of soil 402 to which moisture sensing
15 capacitor 312 is exposed, determines the frequency at which VFO 320 oscillates. Data
16 signal 302 transmitted by probe 300A in response to reception of excitation signal 202
17 transmitted by reader 200 thus has a frequency analogous to the moisture content of soil
18 402 in the vicinity of probe 300A.

19 One important feature of probe 300A then is the fact that it requires no internal
20 energy supply to facilitate its data gathering and data transmission functions. Rather, the
21 energy needed to make VFO 320 oscillate is provided by reader 200 via the inductive
22 couple established between reader 200 and probe 300A. Another important feature of this

embodiment of probe 300A is that rectifier 314A and energy storage capacitor 316A permit electronic circuit 303 to store a relatively large amount of energy with which to cause VFO 320 to oscillate. This large amount of stored energy permits VFO 320 to oscillate at a frequency substantially different than that of excitation signal 202 transmitted by reader 200. As a result, reader 200 is able to readily discern between excitation signal 202 transmitted by reader 200, and data signal 302 received by reader 200 from probe 300A. Further, reader 200 is able to readily receive data signal 302 because data signal 302 is relatively powerful. Finally, because energy must be gradually built up in energy storage capacitor 316A, data signal 302 is transmitted after excitation signal 202 has ceased. That is, there is a time delay between the time excitation signal 202 is transmitted and the time that data signal 302 is transmitted.

As previously noted, another alternative embodiment of probe 300 operates in a "passive" mode. This embodiment, designated in Figure 2C as probe 300B, preferably employs an analog electronic circuit 303 comprising an inductor, in the form of probe receive/transmit coil 304A, and a moisture sensing capacitor 312. The structure and operation of probe 300B are generally similar to that of the embodiment of probe 300 depicted in Figure 2B except that probe 300B does not include an energy storage capability such as is provided by energy storage capacitor 316A of probe 300A (see Figure 2B). Rather, probe receive/transmit coil 304A is energized directly by reader 200. Probe 300B thus requires that reader 200 transmit excitation signal 202 over a broad band so as to ensure that probe 300B is sufficiently energized to effect data acquisition and data transmission. Further, because probe 300B does not employ energy storage

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1 functionality, its analog circuit comprising probe receive/transmit coil 304A and
2 moisture sensing capacitor 312 immediately resonates at substantially the same frequency
3 or harmonic as that of excitation signal 202 transmitted thereto by reader 200.
4 Additionally, the lack of energy storage functionality in electronic circuit 303 of probe
5 300B means that relatively little of excitation signal 202 provided by reader 200 is
6 captured and returned by probe 300B. Hence, data signal 302 transmitted by probe 300B
7 is somewhat less powerful than excitation signal 202 transmitted by reader 200.

8 Specific operational details of reader 200 are discussed in detail elsewhere herein.
9 In general however, the data signal(s) 302 transmitted by probe 300 (or 300A or 300B, as
10 applicable) are received by reader 200 and then processed either by reader 200, or at a
11 remote site 600, to produce a moisture map of agricultural field 400 (not shown). After
12 data signal 302 has been transmitted by the circuit comprising probe receive/transmit coil
13 304A and moisture sensing capacitor 312, receive/transmit controller 318 (or 318A in the
14 case of probe 300A) switches that circuit back to 'receive' mode, thereby readying probe
15 300 (or an alternative embodiment thereof) to receive further transmission of excitation
16 signal 202 from reader 200. As discussed in further detail below, the architecture of
17 reader 200 may be varied as necessary to ensure cooperation with various embodiments
18 of probe 300.

19 Finally, note that while the capacitance value (and thus the moisture content, or
20 soil matrix water potential, of soil 402) can be thus 'encoded' so that the frequency of data
21 signal 302 reflects the capacitance value, this invention contemplates as within its scope
any other methods of encoding the capacitance value that would provide the functionality

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described herein, including, but not limited to, digitally encoding the capacitance value on data signal 302. One possible embodiment of such a digital arrangement is discussed in detail elsewhere herein.

Attention is directed now to a general discussion of the structure and operation of capacitors such as may be employed in the context of the present invention. As is well known, capacitors typically include two conductors electrically isolated from each other by a substantially non-conducting material, or dielectric. In general, the capacitance "C", or ability of the capacitor to hold a charge, is a function of the dielectric constant of the dielectric disposed between the plates of the capacitor. As the dielectric constant of a capacitor varies, the capacitance value of the capacitor, or signal produced by the capacitor upon discharge, will vary as well.

Typically, dielectrics comprise materials that do not materially change over time, thus, the dielectric constant corresponding to that material will likewise remain substantially unchanged over time. However, where the composition of the dielectric varies with time, the dielectric constant, and thus the capacitance of the capacitor, will vary over time as well. Accordingly, the capacitance of the capacitor is a function of the composition of the dielectric of the capacitor.

In the context of a probe 300 employing a digital electronic circuit 303 (one embodiment of which is depicted in Figure 2A), the capacitance produced by moisture sensing capacitor 312 is, as discussed above, analogous to the moisture content of soil 402 in operative contact therewith. Thus, the conversion, by system processor 308 (see Figure 2A), of the capacitance of the moisture sensing capacitor 312, and the subsequent

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1 modulation of that digital carrier signal by output signal modulator 310, results in a
2 digital data signal 302 that indicates the moisture content of soil 402.

3 Where moisture sensing capacitor 312 is employed in a probe having analog
4 circuitry (two embodiments of such a probe being depicted in Figures 2B and 2C,
5 respectively), e.g. 300A and 300B, the effects of moisture sensing capacitor 312 may be
6 appreciated by considering the relationship $f = 1/2 \times \pi(LC)^{1/2}$ which describes the
7 resonant frequency of a circuit employing an inductor and a capacitor. In this
8 relationship, "f" is the resonant frequency, "L" is the inductance of an inductive element
9 such as probe receive/transmit coil 304A, and "C" is the capacitance of moisture sensing
10 capacitor 312. The inductance "L" is a consequence of construction of probes 300A and
11 300B and typically has a fixed value. Thus, the resonant frequency "f" of the electronic
12 circuit 303 employed in probe 300A is determined primarily by the capacitance "C" of
13 moisture sensing capacitor 312. In similar fashion, the resonant frequency of VFO 320 of
14 electronic circuit 303 of probe 300B, is a function of the capacitance "C" of moisture
15 sensing capacitor 312. As previously discussed, "C" varies with the moisture level in the
16 dielectric of moisture sensing capacitor 312 and is thus analogous to the moisture content
17 of soil 402.

18 It will be appreciated from the aforementioned relationship that the respective
19 resonant frequencies of the respective electronic circuits 303 employed in probe 300A
20 and probe 300B are likewise analogous to the moisture level in the dielectric, and,
21 accordingly, to the moisture content of soil 402. Because data signal 302 is transmitted at
22 the resonant frequency of the circuit which includes moisture sensing capacitor 312

(Figures 2B and 2C), the frequency of data signal 302 is likewise analogous to the moisture content of soil 402. Although, in the case of probe 300A, the frequency of data signal 302 may be substantially different from that of excitation signal 202, the frequency of data signal 302 nevertheless is analogous to the moisture content of soil 402. Note that in a preferred embodiment, probe 300 measures the real component of the dielectric constant of hydrophilic dielectric 320 so as to prevent probe 300 from being sensitive to soil 402 conductivity.

Note further that it is also possible to measure the soil matrix water potential in a similar fashion. For this measurement, moisture sensing capacitor 312 is prepared with a dielectric characterized by a known relationship between water content and water potential. When such a dielectric is in contact with the soil for a period of time, the potential of the dielectric will become equal with that of the surrounding soil. Consequently, the water potential of the soil can be determined by employing the measured capacitance in the known relationship between water potential and water content.

With the foregoing principles in view, attention is directed now to the details regarding the structure and operation of various embodiments of moisture sensing capacitor 312, depicted in Figures 3A through 3C. One such embodiment is indicated generally in Figure 3A as 312A. As suggested in Figure 3A, probe 300 includes a shielded wire 322 ultimately connected to system processor 308 (not shown) and having a first conductor 322A and a second conductor 322B. Body 301A of probe 300 is electrically isolated from shielded wire 322 by way of insulation or the like. Moisture

1 sensing capacitor 312A includes two capacitor plates 324, one capacitor plate 324 being
2 connected to first conductor 322A and one capacitor plate 324 being connected to second
3 conductor 322B. When probe 300 is placed in the ground, soil 402 is thereby forced
4 between capacitor plates 324 and thus serves as the dielectric of moisture sensing
5 capacitor 312A. It will be appreciated that the materials, geometry, and/or arrangement
6 of capacitor plates 324 may be varied, either alone or in combination, as required to
7 achieve a desired result.

8 In operation, changes to the moisture content of soil 402 disposed between
9 capacitor plates 324 will cause the dielectric constant "C" of soil 402 to vary. As
10 discussed above, variations in dielectric constant affect the capacitance of a capacitor.
11 Thus, the level of current produced when moisture sensing capacitor 312A discharges is
12 analogous to the moisture content of soil 402. As discussed elsewhere herein, the specific
13 manner in which the output current, or signal, from moisture sensing capacitor 312A is
14 utilized depends on whether or not moisture sensing capacitor 312A is employed in
15 conjunction with digital electronics or analog electronics.

16 In some situations, the properties of soil 402 are so variable that its use as a
17 dielectric could compromise the effectiveness of moisture sensing capacitor 312A. Such
18 would be the case, for example, where the conductivity of soil 402 varies due to changes
19 in ion content. An alternative to moisture sensing capacitor 312A is required in these
20 situations.

21 With reference now to Figure 3B, an alternative embodiment of a moisture
22 sensing capacitor is indicated generally as 312B. As suggested in Figure 3B, probe 300

DETAILED DESCRIPTION

1 includes a shielded wire 322 ultimately connected to system processor 308 (not shown)
2 and having a first conductor 322A and a second conductor 322B. Body 301 of probe 300
3 is electrically isolated from shielded wire 322 by way of insulation or the like. Moisture
4 sensing capacitor 312A includes two capacitor plates 324, one capacitor plate 324 being
5 connected to first conductor 322A and one capacitor plate 324 being connected to second
6 conductor 322B.

7 As further suggested in Figure 3B, capacitor plates 324 are disposed in a portion
8 of probe 300 having a screen 326 or the like so as to permit moisture exchange between
9 soil 402 and dielectric 328 of moisture sensing capacitor 312B. Such an arrangement is
10 particularly desirable where the properties of soil 402 are such that they would interfere
11 with the moisture measurement. Note that the present invention contemplates as within its
12 scope any other device or arrangement that will facilitate the aforementioned moisture
13 exchange, including, but not limited to, perforated materials such as metals, plastics, and
14 the like.

15 With continuing reference to Figure 3B, dielectric 328 comprises a hydrophilic
16 material, preferably ceramic or the like, and thus absorbs a level of moisture consistent
17 with that of soil 402 with which it is communication. Capacitor plates 324 are preferably
18 perforated so as to facilitate movement of moisture between soil 402 and dielectric 328.
19 Changes to the capacitance of moisture sensing capacitor 312B result from moisture
20 exchange between soil 402 and dielectric 328, so that soil 402 moisture content data can
21 be acquired by energizing, and then discharging, moisture sensing capacitor 312B, as
22 described elsewhere herein. Note that the material for dielectric 328 may be chosen for

1 particular properties or characteristics, wherein such properties and characteristics
2 include, but are not limited to, water retention curve, or dielectric loss.

3 It will accordingly be appreciated that the aforementioned methods and devices
4 can also be used to determine soil matrix water potential since the water potential of the
5 soil equilibrates with that of the dielectric. Since, as suggested earlier, the relationship of
6 the dielectric water potential to water content is known, or can be determined, this allows
7 conversion of dielectric water content to soil water potential.

8 It will be appreciated that the materials, geometry, and/or arrangement of
9 capacitor plates 324 may be varied, either alone or in combination, as required to achieve
10 a desired result. Finally, a preferred embodiment of probe 300 further includes a
11 moisture barrier 330 which prevents moisture from coming into contact with shielded
12 wire 322.

13 Directing attention now to Figure 3C, yet another alternative embodiment of a
14 moisture sensing capacitor is indicated generally as 312C. As suggested in Figure 3C,
15 moisture sensing capacitor 312C includes a shield 332 and a center conductor 334
16 disposed in an electrically insulated portion of probe 300. Shield 332 and center
17 conductor 334 have an insulator 336 disposed therebetween so as to substantially prevent
18 electrical communication between shield 322 and center conductor 334. Center
19 conductor 334 extends a predetermined distance beyond shield 332. Such construction
20 causes electrical field lines 336 of electrical field E to extend into soil 402, as indicated in
21 Figure 3C. As is the case with the embodiments of moisture sensing capacitor 312
22 depicted in Figures 3A and 3B, the medium through which the electrical field lines 336

1 pass, i.e., soil 402, determines the capacitance "C" of moisture sensing capacitor 312C.
2 Thus, while the geometry and arrangement of the elements of moisture sensing capacitor
3 312C are somewhat different than that depicted in Figures 3A and 3B, the operational
4 principles are identical, so that as the moisture level in soil 402 varies, the capacitance of
5 moisture sensing capacitor 312C varies in the manner, and with the resultant effects,
6 described elsewhere herein.

7 Preferably, the capacitance measurement, and thus the measurement of the
8 moisture content of soil 402, is made at an RF frequency for which shield 332 and center
9 conductor 334 form a resonant circuit. Such a resonant circuit may be achieved, for
10 example, by constructing and/or arranging shield 332 and center conductor 334 so that
11 the end of center conductor 334 extends outward from shield 332 an electrical distance
12 equal to approximately one quarter (1/4) of the wavelength " λ " of the RF frequency, as
13 indicated in Figure 3C. Such an arrangement has the desirable effect of maximizing the
14 potential, or voltage, between center conductor 334 and shield 332 at that point of center
15 conductor 334 most remote from shield 332, i.e., at the tip of center conductor 334.
16 Consequently, electrical field lines 336 are forced out into soil 402. This arrangement
17 thus serves to maximize the sensitivity of moisture sensing capacitor 312C to moisture in
18 soil 402, and thereby enhance the performance of moisture sensing capacitor 312C.
19 Finally, this arrangement also provides a way to produce substantial probing of soil 402,
20 by electrical field lines, with a sensor that is effectively one-dimensional (i.e., long and
21 thin. Such a geometry and arrangement accordingly permits relatively quick and ready
22 deployment of probe 300 in holes without requiring the careful arrangement of the soil

1 around the conducting elements of the capacitor. Note that both shield 332 and center
2 conductor 334 may be coiled so as to form inductors of relatively increased electrical
3 length, without requiring a physical lengthening of probe 300. Such a coiled arrangement
4 also has the benefit of permitting the "Q" of the circuit to be increased for high electrical
5 potential in probe 300 even in the presence of electrically dissipative soil properties.

6 Directing attention now to Figure 4A, an embodiment of a reader 200 is depicted
7 in block diagram form. In general, the electronics of reader 200 are preferably digital and
8 include a power circuit (generally indicated in phantom lines) and a signal processing and
9 transmission circuit (generally indicated in solid lines). However, the two circuits may in
10 some instances be interconnected so that the portion of the circuit represented by a
11 particular solid line or phantom line in Figure 4A may, at different instances, serve to
12 transmit power as well as facilitate signal processing and transmission.

13 Reader 200 includes a reader transmit/receive antenna 204 having a capacitor 205.
14 Preferably, reader transmit/receive antenna 204 comprises a tuned circuit, antenna, i.e., a
15 resonant antenna, or the like. As previously discussed, reader transmit/receive antenna
16 204 facilitates formation of an inductive couple between reader 200 and probe
17 transmit/receive antenna 304 of probe 300, the inductive couple permitting reader 200
18 and probe 300 to exchange data, and permitting reader 200 to provide energy, in the form
19 of excitation signal 202, to probe 300. Note that in an alternative embodiment,
20 production and transmission of excitation signal 202 is performed by one or more
21 components distinct and separate from reader 200.

Reader 200 additionally includes an input signal demodulator 206 in communication with reader transmit/receive antenna 204, a system processor 208 and an output signal modulator and excitation wave driver 210. System processor 208 includes an input 208A, to which input signal demodulator 206 is connected, an output 208B, to which output signal modulator and excitation wave driver 210 is connected, and a data storage element 208C.

Preferably, input signal demodulator 206 and output signal modulator and excitation wave driver 210 are adapted for, respectively, frequency demodulation and modulation (FM). However, alternative embodiments are contemplated wherein input signal demodulator 206 and output signal modulator and excitation wave driver 210 are adapted for, respectively, amplitude demodulation and modulation (AM). The present invention also contemplates as within its scope input signal demodulators 206 and output signal modulator and excitation wave drivers 210 adapted for, respectively, phase demodulation and modulation. Finally it will be appreciated that input signal demodulators 206 and output signal modulator and excitation wave drivers 210 may be employed that utilize various combinations of different types of demodulation and modulation, respectively.

Power for input signal demodulator 206, output signal modulator and excitation wave driver 210, and system processor 208 is provided by power source 212. The power provided by power source 212 is conditioned and regulated as necessary by power conditioner/regulator 214.

1 In operation, power from power source 212 energizes system processor 208
2 causing system processor 208 to produce a digital carrier signal. The digital carrier signal
3 thus produced is then modulated by output signal modulator and excitation wave driver
4 210, so as to form data component 202A of excitation signal 202 for transmission to
5 probe 300. Excitation signal 202, preferably comprising data component 202A and
6 energy component 202B, is then transmitted from reader 200 to probe 300 by way of
7 reader transmit/receive antenna 204, wherein output signal modulator and excitation
8 wave driver 210 provides the drive to antenna 204 for transmission of energy component
9 202B.

10 In response to transmission of excitation signal 202 by reader 200, probe 300
11 sends data signal 302, in the manner disclosed elsewhere herein, back to reader 200.
12 Preferably, data signal 302 is an FM digital signal, but in other alternatives may take the
13 form of an AM digital signal, or a phase shifted signal, as discussed elsewhere herein.
14 After data signal 302 is received at reader transmit/receive antenna 204, data signal 302 is
15 passed to input signal demodulator 206 which then demodulates data signal 302 so as to
16 extract the digital data from probe 300 for use by system processor 208. In a preferred
17 embodiment, the digital data from probe 300 comprises moisture content data. After data
18 signal 302 from probe 300 has been demodulated, the digital data from probe 300 is
19 stored in data storage element 208C of system processor 208. In a preferred embodiment,
20 the digital data acquired from probe(s) 300 is employed for real-time control of a system
21 in operative communication with the reader, such as an agricultural irrigation system.

1 Finally, a preferred embodiment of system processor 208 includes data link
2 capability so that the digital data stored in reader 200 may be accessed and downloaded
3 from one or more remote sites 600, for processing, manipulation, and/or analysis. Such
4 downloading may occur either automatically based on criteria such as a predetermined
5 time interval, or manually upon request from the remote site.

6 Turning now to Figure 4B, an embodiment of a reader employing analog circuitry
7 is indicated generally as 200A. Reader 200A includes a pulse forming network 203
8 coupled with transmit/receive antenna 304. Pulse forming network 203 forms pulses of
9 excitation signal 202, that are transmitted by transmit/receive antenna 204 to probe 300.
10 In one embodiment, excitation signal 202 comprises radio frequency (RF) energy, or the
11 like. Preferably, reader 200A operates in about a 100 megahertz (mhz) frequency range.

12 As suggested earlier, reader 200 can be used in conjunction with different
13 embodiments of probe 300. Note that, in general, a reader 200 employing digital
14 electronics is preferably employed with probes 300 employing digital electronics.
15 Likewise, a reader 200 employing analog electronics is preferably used in conjunction
16 with probes 300 having analog electronics.

17 In view of the foregoing, reader 200A is preferably used in conjunction with
18 probes 300A (Figure 2B) or 300B (Figure 2C). When used in conjunction with probe
19 300B, reader 200A further includes, in addition to the aforementioned components,
20 blocking circuitry 206, as shown in Figure 4B. In operation, blocking circuitry 206
21 prevents transmit/receive antennae 204 from receiving its own transmissions when it is in
22 'transmit' mode. This is an important feature in view of the fact that when reader 200A is

1 used in conjunction with the embodiment of probe 300 indicated in Figure 2C,
2 transmission of excitation signal 202 from reader 200A and reception of data signal 302
3 by reader 200A occur at substantially the same frequency and the time lag between
4 transmission and subsequent reception is very short. Without blocking circuitry 206,
5 reader 200 could misread its own transmissions as being transmissions from probe 300.

6 If reader 200A is used in conjunction with probe 300A (Figure 2B), blocking
7 circuitry 206 is not required because, as previously discussed, reader 200A transmits at a
8 substantially different frequency than the frequency of data signal 302 transmitted by
9 probe 300A. Furthermore, there is a time lag between the transmit and receive cycles,
10 and thus minimal likelihood that reader 200A would misread its own transmission as
11 being that of probe 300A.

12 With continuing reference to Figure 4B, probe 300A (or 300B) transmits data
13 signal 302 which is then received by transmit/receive antenna 304 of reader 200A.
14 Analog-to-digital converter 209 of reader 200A captures the waveform of data signal 302
15 in memory 210. Software 211 then causes processor 212 to determine the frequency of
16 the waveform of data signal 302 and converts the frequency to moisture content.

17 Finally, note that in an alternative embodiment, transmit/receive antenna 204 is in
18 communication with, but located remotely from, pulse forming network 203, blocking
19 circuitry 206 (where required), analog-to-digital converter 208, memory 210, and
20 processor 212.

21 It will be appreciated that moisture sensor 100 may be profitably employed in a
22 wide variety of applications and for a variety of purposes. For example, the present

1 invention could be configured to measure and report on a wide variety of parameters of
2 various media of interest, wherein such parameters include, but are not limited to,
3 temperature, pressure, voltage, power, current, intensity, wavelength, stress, strain, and
4 pH, and wherein such media include, but are not limited to, liquids (including, but not
5 limited to, water), as well as liquids in combination with solids and/or gases, and thus use
6 of the present invention is not limited solely to agricultural applications, or necessarily to
7 the detection and measurement of moisture content.

8 In one application contemplated by the present invention, moisture sensor 100
9 may be employed to measure water content over a large area for environmental, rather
10 than agricultural purposes, such as in the case of a watershed. In yet another exemplary
11 application of the teachings of the present invention, the moisture content of landfill
12 caps could be monitored in order to facilitate estimates of how much water, or other
13 liquids, will penetrate the cap and thereby lead to potential runoff and pollution problems.
14 In this application, a plurality of probes 300 are disposed throughout a landfill or other
15 site of interest, each of the probes 300 being situated inside a durable structure such as
16 polyvinyl chloride tubing or the like. A portable version of reader 200 is then transported
17 throughout the landfill or site of interest so as to facilitate acquisition of moisture data, or
18 other data, from each probe 300.

19 Finally, the present invention could be profitably employed in the context of
20 various manufacturing or production processes. For example, a plurality of probes 300
21 could be disposed in a process fluid and a reader 200 situated near the path of the process
22 fluid. Reader 200 would then cause passing probes 300 to acquire and transmit data of

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1 interest regarding the process fluid to reader 200. The data thus acquired could then be
2 processed and utilized as required.

3 As suggested elsewhere herein, the present invention is not limited solely to
4 acquiring and processing data. In particular, the present invention contemplates as within
5 its scope, among other things, data acquisition and telemetry for use in facilitating
6 substantially real-time control of one or more systems. The Data Acquisition and
7 Telemetry Control System (DATCS) 700, indicated in Figure 5 is one example of an
8 embodiment of such functionality. DATCS 700 includes a reader 200, a plurality of
9 probes 300, and control module 800. DATCS 700 is in operable communication with the
10 system, or systems, to be controlled, i.e., object system 900. The operation of DATCS
11 700 is described in detail below.

12 Note that because the structure and operation of reader 200 and probes 300 are
13 discussed in detail elsewhere herein, no additional discussion thereof is provided at this
14 juncture. It will be appreciated however, that the features, advantages, operational
15 details, and functionality, disclosed herein, of various embodiments of reader 200 and
16 probes 300 are equally germane in the context of the structure and operation of DATCS
17 700.

18 In operation, reader 200 and probes 300 pass within a predetermined distance of
19 each other so as to facilitate the data acquisition, transmission, and reception processes
20 described elsewhere herein. Note that this invention contemplates as within its scope a
21 variety of arrangements of reader 200 and probes 300 that are effective to facilitate the
22 data acquisition, transmission, and reception processes. Such arrangements include, but

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1 are not limited to, those wherein probes 300 move relative to reader 200, and likewise,
2 arrangements wherein reader 200 moves relative to probes 300.

3 The data acquired by probes 300 and transmitted to reader 200 is evaluated by
4 reader 200 and used to generate one or more sets of instructions corresponding to the
5 acquired data. Alternatively, the data collected by reader 200 is evaluated at remote site
6 600. Remote sites 600 contemplated by the present invention include, but are not limited
7 to, a website on a global computer network. In particular, that data may, as discussed
8 above, be downloaded to one or more remote sites 600, by way of a data link between
9 remote site 600 and reader 200, for processing, manipulation, and/or analysis, wherein
10 such processing, manipulation, and/or analysis include, but are not limited to, generation
11 of a set of instructions corresponding to the data. Such downloading may occur either
12 automatically based on criteria such as a predetermined time interval, or manually upon
13 request from remote site 600. Note that the data acquired by probes 300 may relate to
14 any number of parameters reflecting the environment in which the probes 300 are
15 disposed, including, but not limited to, pressure, temperature, moisture, voltage, power,
16 current, intensity, wavelength, stress, strain, pH, chemical content/composition, humidity,
17 or the like.

18 The instructions generated by reader 200 are then passed from reader 200 to
19 control module 800. In the event the instructions are generated at remote site 600, they
20 are preferably returned to reader 200 and thence to control module 800, but could
21 alternatively be transmitted directly to control module 800. It will be appreciated that a
22 wide variety of processing, manipulation, and analyses may be performed with respect to

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1 the data gathered from probes 300, whether on-location at the site of DATCS 700, or
2 remotely at remote site 600. Accordingly, any data processing, manipulation and/or
3 analyses facilitating the functionality, disclosed herein, of DATCS 700, is contemplated
4 as being within the scope of the present invention.

5 Upon receipt of instructions from reader 200, control module 800 translates the
6 instructions into one or more control signals which are then transmitted to object system
7 900, thereby causing object system 900 to perform the desired action(s). In one
8 embodiment, control module 800 and object system 900 are linked by a feedback loop so
9 that control module 800 is readily able to monitor the performance of object system 900,
10 and, if necessary, make adjustments to the operation of object system 900.

11 In a preferred embodiment, DATCS 700 operates substantially continuously in
12 conjunction with object system 900. As a result of operation in this way, DATCS 700 has
13 the desirable feature of permitting, and effectuating, substantially real-time control of the
14 operation of object system 900. Note that as contemplated herein "real-time control"
15 refers to the capability of DATCS 700 to impose changes on the operation of object
16 system 900 substantially simultaneously with receipt by reader 200 of data gathered by
17 probes 300. Because of this feature, and others enumerated herein, DATCS 700 is well-
18 suited for a wide variety of applications. One possible application concerns agricultural
19 irrigation.

20 As suggested in Figure 6, DATCS 700 may be employed with a center-pivot
21 irrigation system 500. It is also contemplated however, that the present invention could
22 be used in conjunction with a wide variety of other irrigation system types including, but

1 not limited to, linear move irrigation systems or the like. Note that center-pivot irrigation
2 system 500 is but one embodiment of an object system 900 whose operation may be
3 controlled by DATCS 700.

4 In the application depicted in Figure 6, a plurality of probes 300 are disposed in
5 soil 402 of agricultural field 400. It will be appreciated that the number and/or placement
6 of probes may be varied as required to suit a particular application and/or to achieve one
7 or more desired results. Center-pivot irrigation system 500 includes a mobile irrigation
8 structure 502 having a plurality of pivot wheels 504 or the like so as to facilitate
9 movement of mobile irrigation structure 502 over the surface of agricultural field 400.
10 Reader 200 is preferably attached to mobile irrigation structure 502 so that it moves over
11 the surface of agricultural field 400 in conjunction with mobile irrigation structure 502.

12 It will be appreciated that a variety of means may be profitably employed to
13 perform the reader 200 transportation function of mobile irrigation structure 502. Mobile
14 irrigation structure 502 is but one example of a means for transporting reader 200
15 throughout the zone of interest, in this case, agricultural field 400. Thus, the structure
16 disclosed herein simply represents one embodiment of structure capable of performing
17 this function. It should accordingly be understood that this structure is presented solely
18 by way of example and should not be construed as limiting the present invention in any
19 way. An alternate example of means for transporting reader 300 throughout the zone of
20 interest comprises vehicles such as tractors and the like.

21 Reader 200 preferably includes a plurality of transmit/receive antennae 204
22 located at various radii along mobile irrigation structure 502 so as to ensure that all

1 probes 300 disposed in agricultural field 400 will, at some point, be able to communicate
2 moisture content data to reader 200. Note that the same functionality could alternatively
3 be achieved by adapting reader 200 for linear motion along mobile irrigation structure
4 502.

5 Center pivot irrigation system 500 further includes a plurality of nozzles 506
6 disposed at various locations on mobile irrigation structure 502 and being capable of
7 fluid communication with water source 508. Preferably, nozzles 506 are individually
8 controllable so that water flow through each nozzle 506 can be individually regulated. A
9 control module 800 is in operative communication with reader 200 and nozzles 506.

10 As center pivot irrigation system 500 moves across agricultural field 400, reader
11 200 gathers moisture content data from each probe 300, in the manner described
12 elsewhere herein. Note that the present invention contemplates that moisture content, or
13 other, data may be gathered from more than one probe 300 at any given time. Reader
14 200 uses the moisture content data thus gathered to generate a set of watering instructions
15 for control module 800. It will be appreciated that the watering instructions may be
16 generated at remote site 600 (not shown) from reader 200, and then returned to reader 200
17 for passage to control module 800, or alternatively, may be passed directly from remote
18 site 600 (not shown) to control module 800.

19 The aforementioned watering instructions include, but are not limited to, the
20 volume of water to be dispersed, the time(s) when water dispersal is to begin, the length
21 of time for which the required flow rate must be maintained, and/or the location(s) at
22 which the water is to be dispersed. The watering instructions thus generated are passed to

control module 800 which, in turn, transmits one or more corresponding signals to one or more nozzles 506, so as to control the flow of water from water source 508 through nozzles 506 in a manner consistent with the instructions received from reader 200.

It will be appreciated from the foregoing discussion that one valuable feature of the present invention is that it maximizes the efficiency with which water is dispersed on an agricultural field. Because the irrigation system is controlled by way of the real-time moisture content data, water flow can be regulated for optimal dispersion on the field, thereby substantially minimizing wasted water, and significantly reducing water expenses. These are particularly valuable features in areas where water is at a premium and is expensive to obtain.

In a preferred embodiment, reader 200 has stored therein predetermined moisture criteria developed for agricultural field 400, the moisture criteria including, but not limited to, the amount of moisture desired, and the area over which water is to be dispersed. Thus, the moisture content data gathered from probes 300 can be compared to the predetermined moisture criteria, and a set of corresponding watering instructions generated by reader 200 for transmission to control module 800 and implementation by nozzles 506.

As discussed above, the moisture content data collected by reader 200 can be employed to develop a set of watering instructions so as to facilitate real-time control of center-pivot irrigation system 500 by DATCS 700. However, the moisture content data thus collected has a number of other uses as well, one of which is described below.

1 In particular, the moisture content data collected by reader 200 can be used to
2 facilitate development, by reader 200, or alternatively at a remote site 600, of a moisture
3 map of agricultural field 400. The moisture map is preferably contemporaneously
4 produced, and continuously updated, as center pivot irrigation system 500 moves
5 through agricultural field 400. It will be appreciated that transportation of reader 200
6 throughout agricultural field 400 may be accomplished other than by center pivot
7 irrigation system 500, for example, a tractor or the like would provide the necessary
8 functionality of center pivot irrigation system 500 in this regard.

9 Because the moisture map is contemporaneously produced, the farmer has
10 virtually real-time access to the moisture content of the agricultural field 400, or portions
11 of interest thereof. It will be appreciated that maps of parameters other than moisture
12 may be generated as well, wherein such parameters may include, but are not necessarily
13 limited to, chemical composition of soil 402, acidity, and alkalinity.

14 Once the moisture map is generated, it can then be stored in reader 200, or at
15 another site. Preferably, a plurality of moisture maps would be generated and stored so as
16 to facilitate trend analyses and the like with regard to the moisture content of agricultural
17 field 400. It will be appreciated that the same is likewise true with regard to maps of
18 other parameters of agricultural field 400.

19 The present invention may be embodied in other specific forms without departing
20 from its spirit or essential characteristics. The described embodiments are to be
21 considered in all respects only as illustrative and not restrictive. The scope of the
22 invention is, therefore, indicated by the appended claims rather than by the foregoing

1 description. All changes that come within the meaning and range of equivalency of the
2 claims are to be embraced within their scope.